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EXPERIMENTAL STUDY OF THE TURBULENCE PRODUCTION MECHANISM
IN BOUNDARY LAYER FLOWS

by

R. E. Falco

Principal Investigator

Interim Progress Report

Prepared from work done under
Air Force Office of Scientific Research
Contract F49620-82-K-0003

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May 1982

INTRODUCTION

Progress during the first nine months of the contract has been made in experimental techniques, in data acquistion and film quality, in data reduction, in our data base of simultaneous visual and point measurements, and in our knowledge of the physics of turbulence production.

We have learned how to make our laser sheets thinner than previously attained by using both mirrors and lenses. We have learned how to obtain 'almost' continuous data records up to 96 K bytes. We have changed to use of the new non-silvered base Kodak films (this involved a great deal of testing because our exposures are not standard) and now can achieve a better uniformity of image in both the flood and laser sheets. Data analysis programs have been written which allow us to ensemble average the detected events. We have performed a series of experiments in October and November, and a second series in December and January. The first series was made with the four-wire vorticity probe at $y^+=10$. We investigated the flow field associated with the evolution of pockets under fully turbulent boundary layers and under turbulent spots. The turbulent boundary layer data was run through the turbulent detection schemes of Zaric (he visited the laboratory and brought his programs). We found that there was a close correspondence between his detection technique and the passage of pockets. This data was then examined and stored for later processing, and ensemble averaging. The second series of experiments involved simultaneous laser sheet illumination of a slice of flow across the boundary layer, and flood

illumination of the sublayer, along with simultaneous vorticity probe measurements. The algorithms for this data were written and ensemble averages formed. These results have reinforced our earlier qualitative picture of the importance of microscale sweeps which have concentrated vorticity.

The most important results of our investigations to date have been:

1. Vortices of the scale of 100 1^+ exist above pockets during their formation stage (pockets are the footprints of the turbulence production process).

2. These vortices come in pairs, having both downstream and upstream facing orientations. The pairs which propagate upstream (in a relative sense) have been called negative rings, because they would propagate against the flow direction (relatively speaking). It appears that these pairs are rings, and furthermore that they are 'typical eddies' which are in the inner part of the wall region. The pairs which propagate downstream have been called a postive rings, because they would propagate in the positive flow direction. The limited Lagrangian information we have on these pairs does not confirm the hypothesis that they are rings. Investigations on this point are continuing. (see figure 1).

3. Signals from the vortices (which had just formed pockets) were conditionally sampled, and ensemble averages of their velocity, vorticity, Reynolds stress, and a number of turbulence detection functions were

obtained. Figure 2 shows the ensemble averaged values of these quantities at $y^+ = 24$, when a 'positive' pair of vortices creates a pocket. The positive 'u' and negative 'v' indicate that the pair creates a 'sweep'. The Reynolds stress is approximately twice the long time average and the vorticity is less than average at the wire level, even when the streamwise rotating vortex goes through the wire.

4. Figure 3 shows the ensemble averaged values of u, v, uv and the vorticity, when a negative ring (or 'typical eddy') creates a pocket. Once again the positive 'u' and negative 'v' indicate that the ring results in a 'sweep'. The Reynolds stress is approximately 4 times the long time average. The transverse vorticity is significantly less than the long time average. It actually is less on average than the mean vorticity at $y^+ = 24$, meaning that there is rotation of the opposite sign occurring. In this case, these ensemble averages are verifying and firming-up the visual impressions of the occurrence of concentrated regions of vorticity, and they show unequivally, that the eddies which created these pockets were vortex rings, not hairpins, since vorticity of the opposite sign from the mean is not associated with hairpins.

In both cases the strong correlation of the sweep and the vorticity perturbations strongly support the visual information which indicates that vortices of scale $100\ l^+$ are the cause of the pockets, and hence the interaction of these microscale vortices with the wall initiates the turbulence production process. Finally it should be noted that our total sample consisted of 109 pockets, and that 10% did not show visual

indications of vorticity above them as they formed.

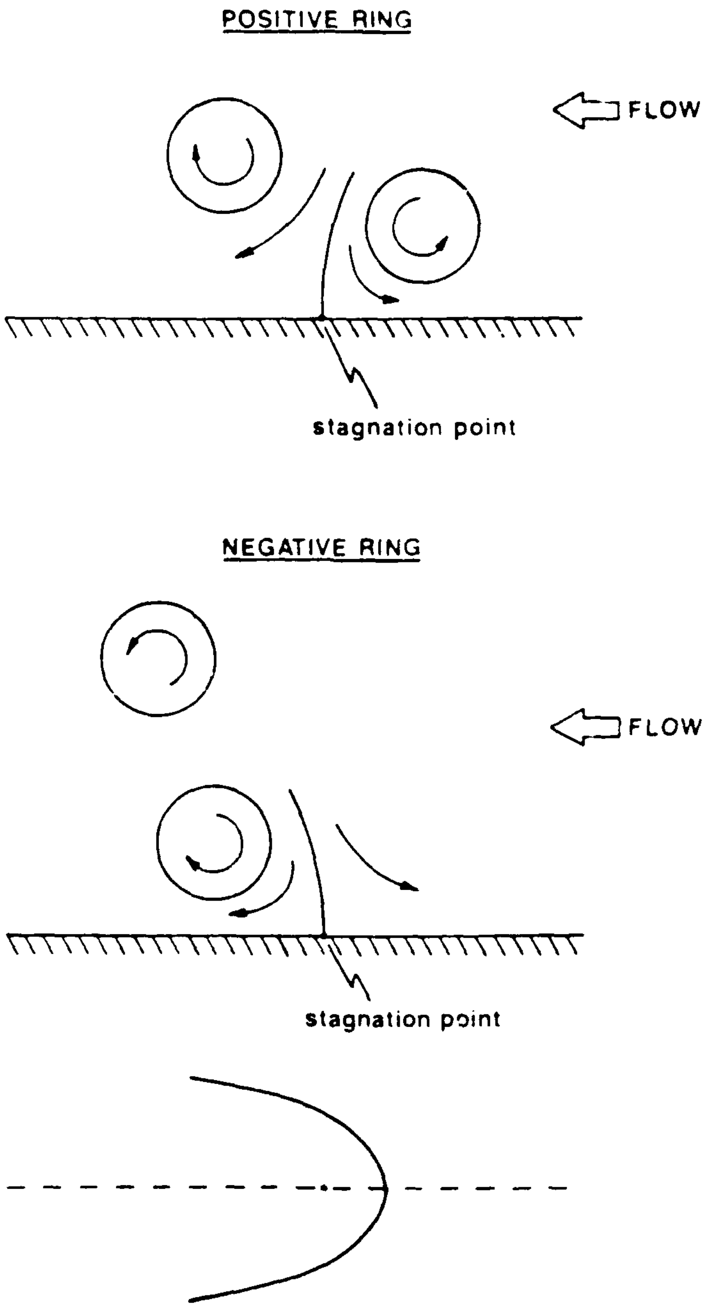

Figure 1. Stagnation Flow Fields Created by Vortex Pairs.

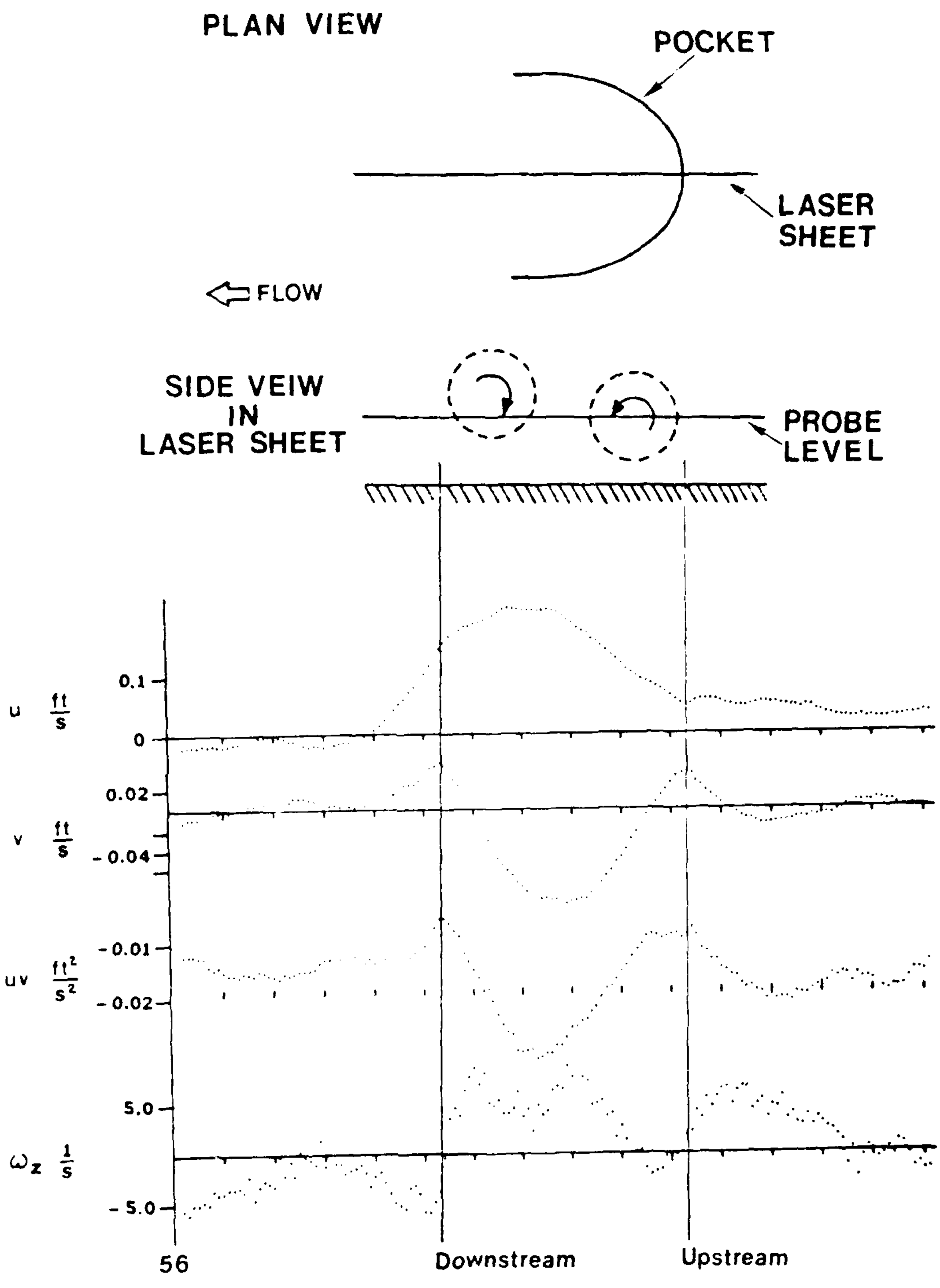

Figure 2. Ensemble Averaged Signals of Positive Rings with High Visual Certainty

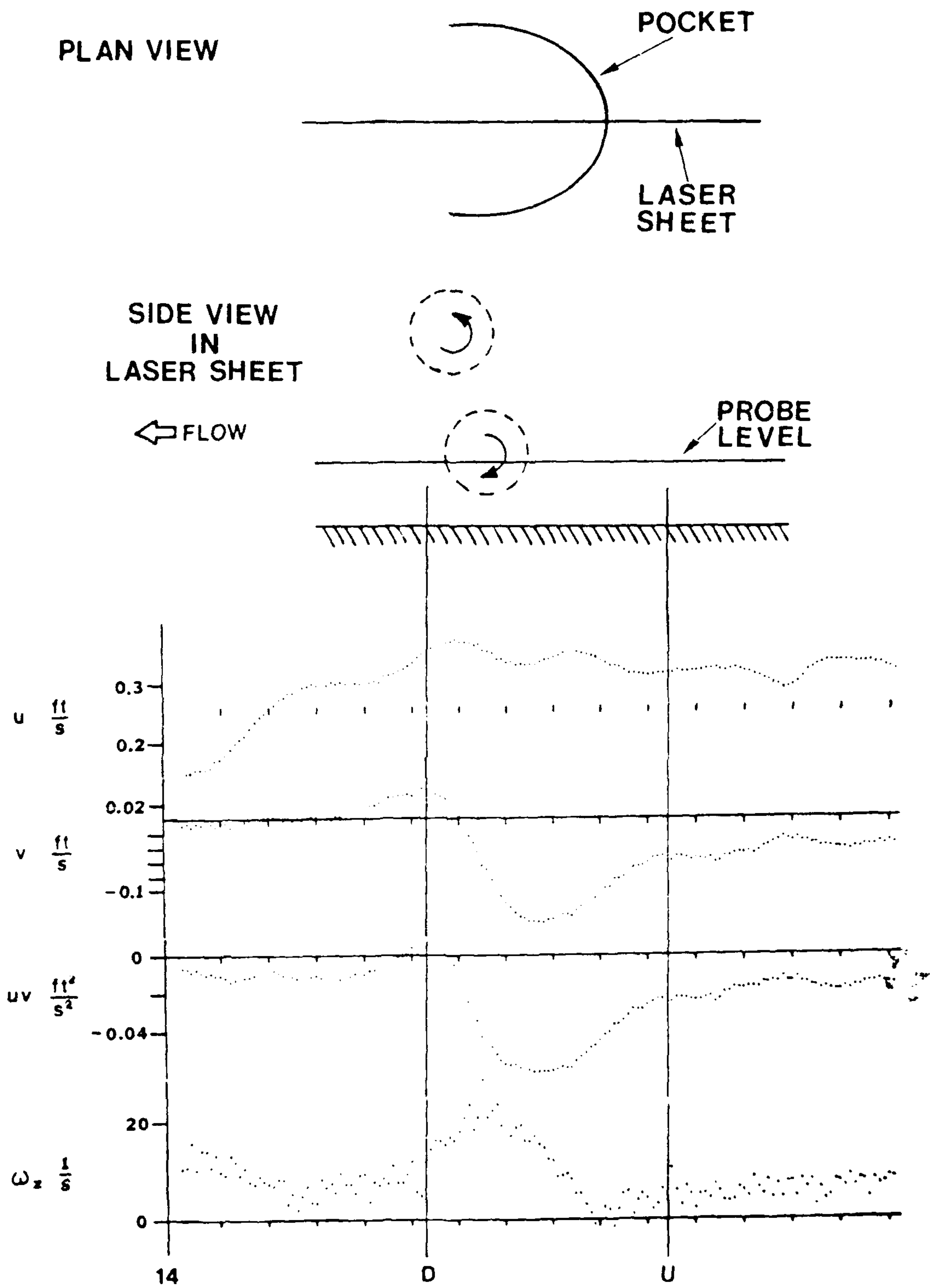

Figure 3. Ensemble Averaged Signals of Negative Rings with High Visual Certainty and Centered Pockets